



The Impact of Intelligent Tutoring Systems and Artificial Intelligence on Students' Motivation and Achievement in STEM Education: A Systematic Review

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Abstract

In recent years, STEM education, which encompasses science, technology, engineering, and mathematics, has experienced significant and dynamic progress. These advancements are characterised by the proliferation of scientific knowledge and the development of cutting-edge educational resources that rely on artificial intelligence technology, among other factors.

A promising avenue for advancing formal education is presented by intelligent tutoring systems, which offer intelligent instruction and feedback, thereby facilitating a more personalized and practical learning experience. This study explored emerging trends and the feasibility of integrating intelligent tutoring systems in STEM education. A systematic literature review was carried out following PRISMA guidelines, with a total of 24 studies included, selected based on predefined inclusion criteria aligned with the research objective. The analysis reveals a growing interest in intelligent tutoring systems within STEM education between 2019 and 2024.

Furthermore, the majority of research conducted thus far has focused on the K–12 education system and higher education institutions. This research initially examined the impact of Intelligent Tutoring Systems on enhancing student motivation and overall academic performance in STEM education courses. The findings substantiate the assertion that integrating artificial intelligence into intelligent tutoring systems positively impacts student motivation and achievement in STEM education. Additionally, students' prior knowledge of STEM subjects enhances their engagement and motivation when using intelligent tutoring systems. Integrating intelligent tutoring systems into STEM education has significantly improved student motivation and academic achievement.

Keywords: Intelligent Tutoring System, Artificial Intelligence, STEM education, Systematic Literature Review.

MSC2020: 97P80

1. Introduction

Education is essential for the advancement of a nation, as it plays a critical role in developing high-quality human capital (Allen et al., 2021; Arslan, 2021; Jehadus et al., 2020). To cultivate capable individuals, students must fulfil the expectations of the educational system and achieve predefined learning goals and tasks (Goldhaber & Ozek, 2019). Most educational systems present grades as a measure of achievement. Today's traditional teaching approach often elevates poorer student achievements (Guterman, 2021). Consequently, learning achievement has become a key

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objective for both teachers and students. This underscores the challenges posed by traditional methods of teaching and learning. With the increasing presence of artificial intelligence (AI) in all fields of human activity, education has not been exempt from its influence. The field of AI has continued to progress rapidly from its beginning to the present, transitioning from theoretical ideas to significant technological breakthroughs. The growing interest in artificial intelligence in education (AIEd) stems from the immense potential of this technology, one of which is the enhanced communication facilitated between educators and learners using virtual assistants. Artificial intelligence in education stimulates the evolution of teaching and learning practices and program design, making it a key domain for educational research (Chiu, 2021a; Chiu, 2023b).

AI has facilitated the development of sophisticated learning systems and adaptive content tailored to individual learner needs. This includes incorporating intelligent virtual reality in simulation-based teaching and learning, which has been proven to promote beneficial outcomes in the learning process (Pokrivcakova, 2019; Saputra et al., 2023). AI holds potential benefits for both students and teachers. For students, it enables uninterrupted learning by offering real-time feedback without requiring the simultaneous online presence of both teacher and learner (Figueiredo & García-Peñalvo, 2020). For teachers, AI assists in creating instructional materials and designing activities to assess student understanding (Jo et al., 2023). An essential potential is the ability to learn uninterrupted, without the requirement for simultaneous online presence of both the teacher and learner. In this context, AI, functioning as a virtual assistant, offers real-time feedback to the student, therefore enabling uninterrupted learning (Figueiredo & García-Peñalvo, 2020). Conversely, AI assists the teacher in developing instructional resources and designing activities to test students (Jo et al., 2023). Nevertheless, AI cannot be perceived as an all-encompassing technology within the world of the technological revolution. However, despite its transformative capabilities, AI should not be viewed as an all-encompassing solution. Certain human attributes, such as creativity and the ability to generate novel ideas or adapt continuously, remain beyond the reach of AI. Integrating AI techniques into ITS aims to provide learning in a meaningful and effective way and actively engage students with an individual, personalized approach to teaching similar to that of a human teacher. The ITS systems analyse each student's actions and characteristics and, based on their learning history and progress, provide personalized guidance such as additional learning content, explanations, tips, examples, and demonstrations. Artificial intelligence techniques, when incorporated into ITS, aim to enhance learning in a meaningful and efficient manner. This is achieved by interacting with students through a personalized, individual approach to teaching, akin to that of a human tutor, facilitated by various computer technologies. In recent years, ITS has demonstrated clear success in helping students make rapid progress, improving their motivation, knowledge, performance, and skills in STEM subjects (Acosta-Gonzaga & Ramirez-Arellano, 2021).

1.1 Aim of the study

This study aimed to examine the challenges identified in empirical research on student motivation in learning, particularly concerning the use of ITS and AI in STEM education. Considering that STEM encompasses four scientific disciplines, it is essential to consider the students' attitudes toward specific disciplines, their preferences for certain fields, and the balanced focus on mathematics, natural sciences, technology, or engineering classes.

This systematic review addresses the following research question:

RQ: How do ITSs with integrated AI impact student motivation and achievement in STEM education?

The remainder of the paper adheres to this framework: Section 2 provides a concise review of the literature on ITSs and the application of AIEd. The methodology approach is outlined in the third section. Section 4 presents the results, thoroughly analysing and addressing the research question. Section 5 discusses the study's findings. The sixth part presents conclusions and implications for further research.

2. Artificial Intelligence and Intelligent Tutoring Systems in the Educational Context

Engaging students actively in their education, despite the diverse range of abilities and motivations, remains a significant challenge for 21st-century schools (Ilić et al., 2024). Growing research on personalized education and active teaching highlights the critical societal demand for equitable educational opportunities for all students (Ryan & Deci, 2020b; Cécile Mazon et al., 2022; Kaat Iterbeke et al., 2021).

Integrating AI in STEM education is rapidly transforming teaching practices by enhancing student engagement and personalising learning experiences. Intelligent tutoring systems (ITSs), which are computerised educational platforms, provide individualised and adaptive guidance, effectively replicating the role of a human teacher (Mousavinasab et al., 2021). AI and machine learning methods are used to assess students' understanding, provide feedback, and customise learning resources and activities to match each student's pace, style, and learning requirements (Nja et al., 2024). Researchers widely agree that student motivation is essential for achieving positive learning outcomes, including engagement, curiosity, and success in STEM education (Fiorella et al., 2021). Ryan and Deci (Ryan & Deci, 2013a) define student motivation as an internal drive that compels students to participate in learning and achieve academic goals. This motivation is crucial for overcoming challenges, enabling students to participate actively in academic activities, persevere through obstacles, and achieve better results (Ramaha et al., 2022). Learning motivation plays a central role in successful learning (Maslow, 1981). Xiong et al. (2015) reported that learning engagement is a strong predictor of learning motivation and vice versa. Intelligent tutoring systems can positively influence student motivation and academic achievement (Xu & Ouyang, 2022). By recognising and responding to the student's emotional and motivational cues, these systems offer personalized support that helps sustain engagement throughout the learning process (D'Mello & Graesser, 2012).

Recent studies highlight that AI can facilitate personalized learning paths, enabling educators to customise educational content to meet individual student needs, which in turn enhances academic performance and motivation (Triplett, 2023; Yekollo et al., 2023; Xu & Ouyang, 2022). Additionally, integrating AI technologies, such as ITS and virtual learning environments, has been shown to foster collaborative learning and critical thinking skills among students (Nagaraj, 2023; Zhou et al., 2023).

Several meta-analyses have been conducted to examine factors influencing student achievement and motivation to learn (Ahmad, 2021; Chen & Hwang, 2020; bin Mohamed et al., 2022). A study by Zheng et al. (2021), which reviewed 24 articles, confirmed that AI had a large effect on student achievement. Lin et al. (2024) analysed the mathematics achievement of students in 21 articles. Their analysis revealed that students who learned using AI and ITSs achieved better results and were consequently more motivated to learn compared to those who were taught through traditional methods such as textbooks, worksheets, and face-to-face instruction.

3. Research Methodology

This systematic review followed the Preferred Reporting Items for Systematic Reviews and the meta-analysis (PRISMA) guidelines as outlined by Moher et al. (2015). The PRISMA Flow Diagram, illustrated in Fig. 1, details the process of study identification and extraction. This systematic review process encompassed four key stages: identification, screening, eligibility, and inclusion.

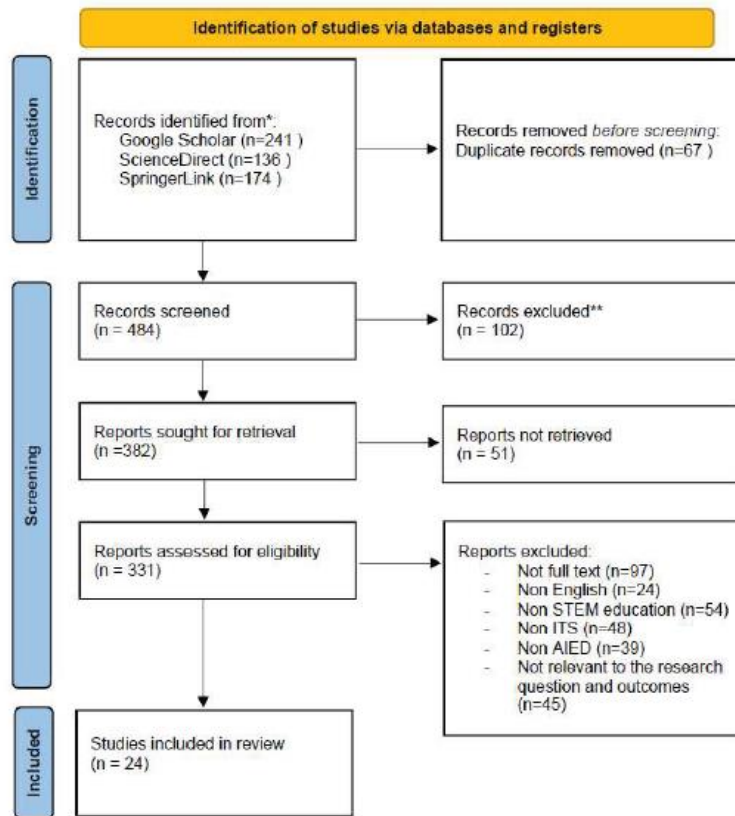


Fig. 1. PRISMA Flow Diagram

3.1 Identification

This systematic review included articles from three databases: Science Direct, Springer Open, and Google Scholar. Relevant articles were identified using a keyword search related to AIED, student motivation, ITSs, STEM education, and K–12 education systems. A combination of keywords and Boolean operators (AND OR) was employed (Table 1). The initial search yielded 136 articles from Science Direct, 174 from the Springer Open database, and 241 from Google Scholar. After identifying and removing 67 duplicate articles a total of 484 unique studies remained. The review focused exclusively on peer-reviewed articles, excluding grey literature, to ensure the inclusion of studies meeting scientific community standards.

Table 1. Search equation

Connector	Keyword
AND	“Intelligent Tutorial System” OR “Expert Systems” OR “Artificial Intelligence in Education” OR “Intelligent Tutoring System with Artificial Intelligence”
AND	Math OR maths OR mathematics OR mathematical OR "math education" OR “Mathematics education” OR “mathematical sciences” OR “learning of mathematics” OR “Mathematics teaching”
AND	STEM OR stem OR STEM education OR “learning of STEM” OR “STEM teaching”
AND	Programming OR coding OR “programming education” OR “Programming lesson” OR “computer science education”

3.2 Screening strategy

The initial screening stage involved a detailed review of each article's abstract to assess its relevance and suitability. This study considered publications from the timeframe of 2020 to May 2024. The review focused exclusively on English-language journal articles that addressed student motivation in STEM education, ITSs, and the role of AI in this field. In the first screening phase, 102 out of 484 articles were excluded. The main research topics were AI and ITSs within STEM education, covering subjects such as science, physics, mathematics, technology, and engineering education. This research encompasses empirical studies with control and comparison groups, and meta-analyses.

Table 2. Screening criteria

Criteria	Inclusion	Exclusion
Publication Timeline	2020 – 2024	Published before 2019
Document Type	Journal or conference paper	Other document types (e.g., books)
Language	English	Not in English
Nature of the study	Concentrate on student motivation issues in aide and ITS	Not focus on student motivation and achievement in AIED and ITS

3.3 Eligibility and Inclusion in Research

Following the first screening cycle, 148 papers were excluded, leaving 166 papers for further review. The next step involved a second level of screening to more rigorously evaluate the quality of the paper based on the criteria outlined in Table 2. This stage assessed whether the research goals and objectives were clearly defined and executed, focusing on aspects such as the methodology, data collection and presentation, both qualitative and quantitative, and reporting of research data. Additionally, the study considered the characteristics of the target group involved.

Table 3. Assessing article quality criteria

No	Criteria	Descriptions
1	Study context	Does the article effectively communicate the research process?
2	Objectives and purposes	Are the study's aims clearly defined in the article?
3	Methodology	Does the article comprehensively explain the research methodology, including the framework, data collection, and data analysis?
4	Data	Are materials such as transcripts and feedback included? Does the material demonstrate clarity and thorough analysis?
5	Results validation	Were the results validated? Did the researcher use peer review or feedback to confirm the findings?
6	Sample	Does the article provide an adequate sample size for the research conducted?

In addition, the relevance of the findings to the stated research questions will be assessed and evaluated, along with the contributions of each study. Papers will be carefully reviewed for their practical implications to ensure a comprehensive understanding of the research impact. A key focus will be on transparency in the research process, particularly whether the authors provide sufficient detail about their experimental or analytical procedures to allow reproducibility and

validation of results. The objective of the screening is to select high-quality studies that meet the criteria and offer a credible contribution to the academic community.

The second level of screening, the paper quality check, is the next step. Table 3 outlines the criteria that guided the screening process. It is essential to determine whether the research goals and objectives are clearly defined and properly executed. Another critical aspect is the methodology, including the methods of analysis, data collection, and presentation of both qualitative and quantitative data. Additionally, attention must be paid to how the research data is reported and presented. Finally, examining the characteristics of the target group involved in the study is crucial.

Using the previously defined search criteria, relevant research articles were identified in digital libraries. After applying the inclusion and exclusion criteria, 24 articles were selected for this study. Each article addresses the use of ITS in STEM education. Given that AIED influences various outcomes, this paper focused on analysing 24 studies that examine student achievement and learning motivation (Table 4).

Table 4. Summary of included articles

Year	Authors	Descriptions
2020	Gunawan, K. D. H., Liliyasi, S., Kaniawati, I., & Setiawan, W.	Research shows that using ITSs in science lessons can increase student motivation and engagement in blended learning.
2020	Akyuz, Y.	ITSs do not significantly affect student engagement.
2020	Hasan, M. A., Noor, N. F. M., Rahman, S. S. B. A., & Rahman, M. M.	A review indicates that incorporating emotional and social elements in tutoring systems minimally affects student motivation.
2020	Hartanto, B., & Reye, J.	The paper explores “anchored instruction” in tutoring systems to boost engagement and understanding in programming through context and hands-on activities.
2021	Shin, D.	The paper notes that ITSs boost student motivation, but success relies on future teachers’ TPACK understanding.
2021	King, C. L., Vincent, Kelvin, Warnars, H. L., Nordin, N., & Utomo.	The results of research on ITSs for sixth-grade arithmetic reveal that individualised and interactive learning increases student motivation.
2022	del Olmo-Muñoz, J., González-Calero, J. A., Diago, P. D., Arnau, D., & Arevalillo-Herráez, M.	Research indicates that incorporating flexibility in ITSs enhances students’ arithmetic skills and outcomes.
2022	Xu, W., Ouyang, F.	A systematic review reveals that AI in STEM education boosts student motivation through interactive teaching while also facing challenges related to implementation and resources.
2022	bin Mohamed, M. Z., Hidayat, R., binti Suhaizi, N. N., bin Mahmud, M. K. H., & binti Baharuddin, S. N.	In a systematic review of AI in mathematics education, the authors note that interactive and personalized learning methods can motivate students, but challenges such as access to resources and teacher training remain.
2022	Ramaha, N. T., Abdellatef, H., & Karas, I. R.	The article highlights that students become more engaged and interested in learning when they utilise the ITS, which motivates them with targeted and engaging tasks.
2022	Susilawati, A., Yusrizal, Y., Halim, A., Syukri, M., Khaldun, I., & Susanna, S.	PhET simulations and ITS systems boost motivation and problem-solving in physics, creating a more engaging learning experience.
2023	Huang, Y., Brusilovsky, P., Guerra, J., Koedinger, K., & Schunn, C.	The research describes how an ITS may help students integrate coding and code-tracking abilities, with findings showing that effective learning and practical application enhance motivation.
2023	Zhu, Q., & Wang, M.	The paper examines team-based mobile learning supported by an intelligent system for STEM students. The results indicate that this

		approach significantly increases student motivation and interest through interactive activities and collaboration.
2023	Jia, F., Sun, D., & Looi, C. K.	The paper reviews a decade of research on AI in science education to engage students in STEM, addressing various challenges related to research and implementation.
2023	Hebebcı, M. T.	The research investigates the use of AI in STEM education and finds that tailored and engaging teaching methods can enhance student motivation.
2023	Triplett, W. J.	The article explores team-based mobile learning using an intelligent system for STEM students. The findings show that this approach significantly increases student motivation and interest through interactive, collaborative learning activities.
2023	Nagaraj, B. K., Kalaivani, A., Begum, S., Akila, S., & Sachdev, H. K.	Research delineates the advantages and obstacles of artificial intelligence in STEM education. Artificial intelligence augments education via customisation, data analytics, and enhanced pedagogical techniques while fostering cooperation and increasing motivation.
2024	Abdul-Rahaman, A. M., & Tindam, T. N.	The study shows that STEM education boosts student interest and engagement, ultimately improving academic performance.
2024	Ramadhan, A., Warnars, H. L. H. S., & Razak, F. H. A.	In a systematic review of combining ITS and gamification, the authors indicate that this integration can significantly increase student motivation through engaging and enjoyable teaching methods that promote active learning.
2024	Zouhri, A., & EL Mallahi, M.	The paper discusses how AI and augmented reality improve teaching by greatly increasing student motivation and knowledge through interactive learning experiences.
2024	Wardat, Y., Tashtoush, M., AlAli, R., & Saleh, S.	Research demonstrates that AI can enhance student engagement through personalized teaching, though a lack of teacher training and resources may limit its use.
2024	Clément, B., Sauzéon, H., Roy, D., & Oudeyer, P. Y.	The study shows that machine learning-based tutoring systems can boost performance and motivation, fostering active learning.
2024	Joseph, O. B., & Uzundu, N. C.	Integrating AI and machine learning in STEM education can enhance student motivation and learning, though challenges such as limited teacher training and technical resources remain.
2024	Niño-Rojas, F., Lancheros-Cuesta, D., Jiménez-Valderrama, M. T. P., Mestre, G., & Gómez, S.	Research results show that ITSs significantly increase students' motivation to learn mathematics through personalized approaches and interactive feedback.

The results of the study indicate that the majority of the research selected, following the PRISMA methodology and the application of exclusion and inclusion criteria, was published between 2020 and 2024 (see Fig. 2).

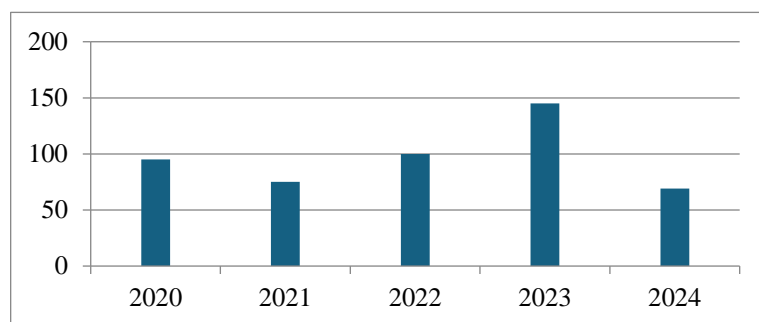


Fig. 2. Statistics of articles per year

This study focused on the application of ITS in STEM education, with particular emphasis on computer science (percentage = 36.1%), mathematics (percentage = 53.2%), and science (percentage = 21.5%).

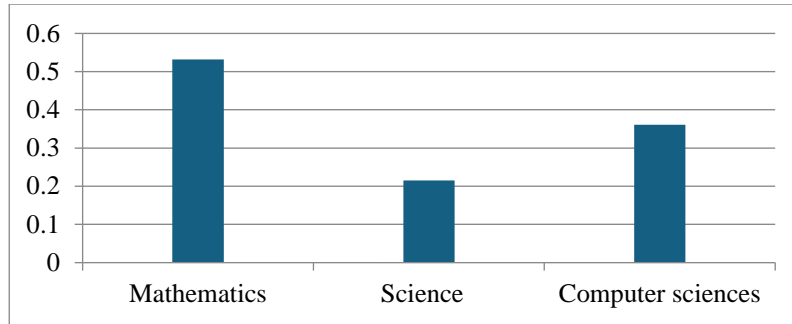


Fig. 3. Education fields of ITS

Improvements in student academic performance have been reported due to the availability of additional learning materials provided by ITS and AI in STEM education (Lei et al., 2021; Zheng, 2019). Table 5 outlines the added efficiencies of ITS and AIED in STEM education, along with a notable increase in academic achievements.

Table 5. Effectiveness of ITSs use

Subcategory	Number of studies	Percentage (%)
Improve learning	11	45.83
Improvement in academic performance	17	70.83
Increases motivation	15	62.5
Encourages personalized and adaptive learning	14	58.33

The majority of studies (percentage = 41.86%) highlight the importance of personalisation and customisation in learning. Some ITSs incorporate real-time chat features, enabling students to receive immediate feedback on any questions. These systems address both cognitive and emotional needs by offering personalized and adaptive learning plans tailored to each student’s deficiencies and special requirements, which helps to overcome learning challenges and improve academic performance.

Moreover, ITSs and AI significantly enhanced the overall learning process, with improvements reported in 24.75% of cases. Motivation, a crucial factor in mastering new teaching materials, plays a key role in these improvements. Numerous studies (N = 17) confirm that students experience a significant increase in motivation when using ITS. This rise in motivation, coupled with personalized teaching approaches, leads to improved academic achievements in STEM subjects (N = 15).

4. Results

The results section addresses the research questions by delineating two primary themes: (1) the impact of ITSs on learning motivation and (2) the characteristics of ITSs for STEM teaching. A key consideration is whether the articles included in the sample provide an adequate sample size for the research conducted. All articles selected were published between 2020 and May 2024.

The review process identified 24 articles that analysed the impact of ITS and AI on student achievement and motivation in STEM classes. Out of these, 4 independent studies reported a negative effect, while 20 demonstrated a positive impact on enhancing students’ motivation and academic achievement.

Following an analysis of the study’s heterogeneity and specificity analysis (looking at overall effect sizes with different learning topics in STEM subjects, types of AI, and samples), the findings confirm that students in K–12 were generally more motivated, regardless of the type of ITS or AI employed. This positive effect on motivation can be attributed to both cognitive enhancement and

affective development. AI supports students in developing a positive attitude toward STEM subjects, particularly mathematics, science, and computing ($N = 21$). As a result, students are more engaged and willing to dedicate additional time and effort to learning these subjects (Table 6). However, several studies ($N = 3$) reported no significant effects of AI on student achievement or motivation.

Table 6. Number of published papers by STEM discipline

STEM discipline	Positive	Negative
Mathematics	10	2
Computer science	7	1
Science	4	0

These findings suggest that students can engage in meaningful STEM learning with high levels of motivation, leading to improved knowledge, skills, and achievement in STEM subjects.

Regarding the impact of AI technology on student motivation and achievement in STEM education, a total of 824 respondents were identified across 24 studies. This includes mathematics teaching ($N = 397$, percentage = 48.17%), computer science teaching ($N = 231$, percentage = 28.03%), and physics classes ($N = 154$, percentage = 18.68%). The analysis showed that among the total number of respondents (824 students involved in 24 studies), only 5.1% struggled to maintain focus on their studies, leading to a loss of motivation and subsequently lower academic achievement when using AI (Table 7).

Table 7. The sample for examining motivation and achievement

Sample	Positive	Negative
Mathematics	397	15
Computer science	231	16
Science	154	11

The study involved various types of ITS. ITS platforms with intuitive interfaces that were easy to use generated more interest among students ($N = 11$, percentage = 45.83%). Numerous studies ($N = 14$, percentage = 58.33%) have shown that students who used ITS with features such as visualisation and simulation showed increased motivation. This effect was especially prominent in the teaching of mathematics, particularly in geometry.

Of the total number of studies, the majority ($N = 14$, percentage = 73.68%) confirmed that students using ITS achieved better results compared to those studying through traditional methods. Three studies (percentage = 15.79%) indicated no significant difference in achievement between students using ITS and those in traditional classrooms. However, a small number of studies ($N = 2$) reported that students using ITS performed worse than those in traditional settings (Table 8).

Table 8. Student achievement in STEM ITS education

	Positive	Neutral	Negative
Number of Articles	14	3	2
Percentage	73,68	15,79	10,53

Most of the analysed publications indicated that AI technologies had a positive impact on students' affective perceptions, including attitude, interest, and motivation ($N = 12$, percentage = 63,16%).

To better understand how AI technologies integrated into ITS contribute to improved outcomes in STEM education, the study investigated the impact of these technologies on student achievement. The improved performance is largely attributed to the increase in positive motivation among students learning with ITS.

5. Discussion

This systematic sought to evaluate how ITS and AI influence student motivation in STEM education. Specifically, the analysis addresses how ITS integrated with AI affects student motivation and achievement.

The findings demonstrated the potential use of AI systems and ITS in STEM education. Intelligent AI-based tutoring systems assist in acquiring knowledge that aligns with unique characteristics and specific needs, providing teachers and students with valuable feedback that steers them toward effective learning strategies. Studies have shown that AI positively impacts student outcomes, particularly by increasing motivation and enhancing academic performance. Research consistently shows that students who regularly use ITS achieve better academic results compared to those relying solely on traditional learning methods.

The personalized learning approaches provided by ITS contribute significantly to its effectiveness by adapting to individual student needs and offering immediate feedback, significantly improving understanding and retention of material. Meta-analyses indicate that ITS implementation can increase student engagement and motivation, especially in subjects such as math and science. The interactivity and tailored support of these systems foster a more engaging learning environment, encouraging students to take an active role in their education. Additionally, the ability to receive instant feedback helps students quickly identify and address their weaknesses, leading to a deeper comprehension of complex concepts.

However, the success of ITS depends on several factors, including the system's design, the subject being taught, and the educational context. This highlights the importance of integrating ITS with traditional teaching methods to achieve optimal results. A blended learning approach that combines both ITS and traditional methods can capitalise on the strengths of each, offering students a more comprehensive educational experience.

In summary, the integration of ITSs and AI shows great potential for enhancing student motivation and academic achievement in STEM education. By focusing on the interactions between motivational factors, educators can create more effective learning environments that cater to the diverse needs of their students, ultimately fostering a richer and more engaging educational experience.

6. Conclusions and Implications for Future Research

This systematic literature review examined studies focused on the role of AI in K–12 STEM education, particularly regarding the implementation of ITSs. A thorough review of scholarly literature was conducted, with publications selected from significant databases such as Science Direct, Springer Open, and Google Scholar. This analysis encompassed 24 publications that provided valuable insights into students' motivation and achievement in STEM education using ITSs and AI in education. The findings indicate that these technologies not only enhance personalized learning experiences but also promote greater engagement among K–12 students. By providing customised feedback and offering adaptive learning pathways, ITS and AI contribute to improved academic achievement and foster increased interest in STEM disciplines.

Each study in this review has certain limitations. Despite ITS being one of the most extensively researched AI applications in education, the limited number of relevant articles included in this analysis was somewhat surprising. Factors such as the selection of databases, inclusion and exclusion criteria, and potential publication and reporting biases may have constrained the scope of this review. More research is needed to thoroughly assess the impact of ITS on learning and performance in elementary and secondary (K–12) STEM education.

Future research should focus on evaluating the effects of ITS and AI in STEM education over extended periods, with larger and more diverse sample sizes that encompass all educational levels,

including university and high school students, not just K–12. It is also important to consider different educational systems worldwide. For example, future studies could explore the potential differences in ITS outcomes between male and female students across various countries, comparing results in both economically developed and underdeveloped nations.

Subsequent investigations should prioritise long-term studies to assess the impacts of ITS and AI in STEM education using larger and more varied sample populations. These studies should include students from a range of educational backgrounds and account for the diverse educational systems found in different countries. For instance, examining gender disparities in several countries—spanning both economically advanced and financially disadvantaged contexts—could provide valuable insights.

This systematic review highlights the transformative potential of ITS and AI in improving STEM education for K–12 students. As educational institutions continue to adopt these technologies, ongoing research and development will be essential to maximise their effectiveness and ensure equitable access for all students. The findings strongly support the continued exploration of innovative educational technologies, aiming to create more engaging and effective learning environments in STEM education.

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